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(6) THE EFFECTS OF LOW FREQUENCY NOISE ON MAN AS RELATED TO THE APOLLO SPACE PROGRAM,

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32385.

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THE EFFECTS OF LOW FREQUENCY NOISE ON MAN AS RELATED TO THE APOLLO SPACE PROGRAM

SECTION I

INTRODUCTION

The purpose of this report is fourfold: (1) to present best estimates of the maximum low-frequency noise environments (5-1,000 c/s) expected inside the command module of the Apollo space vehicle during launch operations; (2) to summarize the capabilities of several existing noise sources which are available to simulate these estimated environments for laboratory and field study purposes; (3) to document known exposure histories to this type of noise including newly conducted experiments with human test subjects; and (4) from this documentation to draw conclusions concerning the significance of low frequency noise in Apollo space vehicle operations.

The requirement for the subject study is based upon the fact that the level of very low frequency noise (1-100 c/s) generated during a launch operation generally increases as the vehicle increases in size and thrust. It has been estimated that the very large super boosters of the future (e. g., NOVA) will produce their maximum noise energy in the infrasonic frequency range (i. e., below 20 c/s). The effects of such high level, low frequency noise on structures, equipment and man are largely unknown and it is only recently that active efforts have been undertaken to evaluate these potential problems.

This report is limited to considering only the noise environments estimated external to and within the Apollo command module and the significance of these environments insofar as the crew members are concerned. Effects of the higher level noise anticipated for the more advanced vehicles are not within the scope of this particular study. Subsequent phases of a much broader research program currently being conducted by this Laboratory will include determination of absolute physiological tolerance limits and biomechanical response characteristics of the whole body and its various parts to the latter type of acoustic excitation. The dynamic pressure chamber being developed by this Laboratory will serve as the basic tool in these long range studies.

SECTION II

ESTIMATED ENVIRONMENTS FOR APOLLO LAUNCH

For purposes of estimation, it was assumed that the Apollo vehicle would be launched by the advanced Saturn C-5 booster vehicle with five clustered F-1 engines of rated thrust, gas velocity, flow rate and nozzle diameter.

Two major sources of noise must be considered to describe the environment surrounding and within the command module: (1) the booster propulsive flow and (2) the aerodynamic boundary layer turbulence on the surface of the moving vehicle.

TIME HISTORIES OF OVERALL SPL's:

The first of the sources, the propulsive flow, generates acoustic energy as a result of the turbulent mixing of the propulsive flow with the surrounding atmosphere. In general the frequency band containing the peak energy is directly proportional to the effective gas velocity and inversely proportional to the effective flow diameter. This source of noise is the controlling factor in establishing the noise environment while the vehicle is still on the launch pad and immediately following lift-off.

The time histories of Figure 1 present the estimated average overall sound pressure levels (SPL in dB re 0.0002 dyne/cm^2) external to and within the command module. Note that as the vehicle accelerates off the pad, the estimated SPL's decrease, primarily as a result of the decreasing velocity of the propulsive flow relative to the surrounding atmosphere. Approximately 25 seconds after ignition, the SPL's reach a relative minimum at which time the second source of noise, aerodynamic turbulence becomes important.

As the vehicle continues to accelerate through the atmosphere, the magnitude of the turbulent eddies convected over the surface of the vehicle increases causing a proportional increase in the vibrational energy transmitted through the walls of the vehicle and radiated within the vehicle. This noise reaches a maximum approximately one minute after ignition as the vehicle is undergoing maximum dynamic pressure (max q). Then, as the vehicle lifts sufficiently above the denser atmosphere, this boundary layer turbulence progressively decreases such that the associated noise levels are relatively insignificant approximately two minutes after ignition.

Estimation of the external noise environments from engine and vehicle parameters is accomplished by extrapolation of existing experimental data. General agreement exists that this procedure (Ref 1) results in the best estimate possible. The attenuation of the external levels to those within the module will be considered somewhat later in this section, but at this point it can be observed on Figure 1 that an attenuation of the overall SPL of 30 dB is estimated.

SPECTRA OF MAXIMUM LEVELS:

There are four operational situations which are of significance insofar as this evaluation is concerned, because it is during these particular situations that the maximum SPL's are estimated to occur. The spectra for these four operational conditions are given on Figure 2 for the average levels occurring over the external surface of the command module and for those average levels within the module. (For command module attenuation see below.)

Although normal launch operations are of prime concern herein, the two abort situations are included for sake of completeness. In these cases the noise produced by the propulsive flow of the abort engines has been included in estimating the environments. Also, primary attention is devoted herein to those levels within the command module where the crew members will be located. The external levels are of importance only insofar as they contribute to evaluating and understanding the internal environments.

The reader's attention is directed to the fact that Figure 2 and subsequent figures present sound pressure spectrum levels as functions of frequency. Spectrum level at a specified frequency is defined as the sound pressure level expressed in dB re. 0.0002 dyne/cm^2 within a band 1 c/s wide centered at that frequency. The use of spectrum level provides a necessary and convenient means for intercomparing various data analyzed with equipment of different band widths (e. g., octave band, 1/3 octave band and narrow frequency). The conversion factors to apply to spectrum levels at selected American Standards Association preferred frequencies to convert to octave band SPL's are tabulated below where the indicated frequencies are the geometric mean center frequencies of the respective bands.

TABLE I

CONVERSION FACTOR TO BE ADDED TO SPECTRUM LEVEL TO OBTAIN OCTAVE BAND LEVELS

Frequency (c/s)	Conversion Factor (dB)
6.3	7
12.5	10
25	13
50	16
100	19
200	22
400	25
800	28
1600	31
3150	34

Under normal launch conditions, the most severe noise environment (Figure 2) is estimated to occur during max q (Mach 0.7-1.1) with the level inside the module peaking at approximately 108 dB in the 50-80 c/s frequency range. The on pad normal launch noise will be approximately 12 dB lower in the same frequency range.

Only if an abort should be initiated during high q will the crew be exposed to a low frequency environment any more severe than that indicated for max q normal launch. In this abort case, levels would be approximately 6 dB greater for frequencies below 300 c/s.

COMMAND MODULE ATTENUATION:

The noise attenuation characteristics estimated for the command module are indicated on Figure 3 where they are compared with estimated and measured attenuation values for the Mercury capsule. The attenuation of sound outside the module to the level produced within is, of course, frequency dependent; attenuation in the upper frequencies is controlled by the mass of the isolating structure while the low frequency attenuation is controlled by the structural stiffness.

It would appear that the Apollo command module attenuation estimates made by North American Aviation, Inc. (Ref 1) are conservative compared with those measured on the Mercury capsule. North American has indicated (verbal communication, Mr. Clay Stevens, 31 Dec 63) that they consider their estimates to be conservative in view of the stiffness inherent in the command module design. Additional panel tests are currently being undertaken by NAA to further validate these low frequency attenuation estimates.

Since the spectra of noise external to the command module peak in the 50-80 c/s range, an attenuation of 30 dB has been assumed to apply to the overall SPL time histories presented on Figure 1.

SECTION III

SOURCES FOR LABORATORY SIMULATION OF ENVIRONMENTS

To adequately assess the effects of the low frequency noise environments estimated, it is necessary to have available one or more noise sources capable of simulating in part or in total the required test spectra so that subjects may be exposed under controlled conditions.

The capabilities of several existing and soon to be available facilities are compared on Figure 4 to the two most severe environments which have previously been estimated as occurring within the command module: one during max q normal launch and the other during a high q abort.

Also indicated on Figure 4 are the upper limiting levels proposed by NASA-MSC for this study. It would appear that these proposed levels are unrealistically high and exposure of subjects to these levels would represent severe overtesting insofar as the Apollo mission requirements are concerned.

AMRL HIGH INTENSITY SOUND SYSTEM:

Two noise sources immediately available to AMRL can produce SPL's in excess of those anticipated within the command module. One of these sources is an AMRL high intensity electrodynamic system which can be programmed with any suitable electrical signal input. Figure 4 indicates the maximum levels obtainable with this system using octave bands of white noise one at a time and the low frequency portion of this system. The spread in level represents the variation in SPL as measured at different locations in the central part of the 5,000 ft.^{3} test chamber. As will be seen later, this same system can simulate the broad band spectrum (10-1,000 c/s) at somewhat lower levels.

TURBOJET ENGINE:

The second source immediately available to AMRL is the turbojet engine which produces a very realistic simulation of the desired test spectra at certain locations in the so-called near sound field of the engine. For example, at a location approximately 50 ft. downstream and 25 feet offstream of an F-102 aircraft (J57 engine) operating with afterburner, the spectrum of the noise environment as shown on Figure 4 is of similar shape to that estimated within the command module during max q normal launch. Levels approximately 15 dB higher than those expected in the module may be obtained across the frequency range with this noise source.

ASD LOW FREQUENCY SIREN:

The USAF-ASD low frequency siren currently being installed at Wright-Patterson AFB will have the capability indicated on Figure 4 from 3-25 c/s with distortion not exceeding 30%. This facility is suitable for testing with human subjects and will be available for test purposes in February 1964 if desired.

NASA-LANGLEY SIREN:

The discrete frequency siren at NASA-Langley is capable of producing levels up to approximately 140 dB (40-100 c/s) with less than 30% harmonic distortion as also shown on Figure 4. Levels up to 170 dB can be obtained with greater distortion. The capability of this siren improves above 100 c/s but is not shown on Figure 4 since the frequency range of prime interest in this study lies below 100 c/s.

NASA-LANGLEY THERMAL STRUCTURES TUNNEL:

Another source of low frequency noise at NASA-Langley is the 6 X 9 ft. Thermal Structures Tunnel. The broad band noise spectrum produced by this blowdown facility at a location 480 ft. from the tunnel exhaust is given on Figure 4. Levels considerably higher of various spectral content can be obtained at locations nearer the source. No detailed data in the low frequencies were available, however, for other locations.

AMRL DYNAMIC PRESSURE CHAMBER:

The operating range of the USAF-AMRL Dynamic Pressure Chamber presently

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under development is included on Figure 4. Present design specifications require performance as indicated from 0.5-30 c/s. Extension of this capability to 100 c/s as shown, is being considered at this time. This chamber was designed to simulate low-frequency noise fields of the very large boosters programmed to follow Saturn, and therefore, it will be able to operate at much higher levels and at much lower frequencies than those of immediate concern in the subject Apollo evaluation. Estimated operational date: June 1964.

NASA-LANGLEY LOW FREQUENCY NOISE FACILITY:

This facility will be availab[illegible] and will be suitable for testing with human subjects. Performance capability is estimated to be 165 dB (1-50 c/s) random or sinusoidal, maximum.

SECTION IV

EXPOSURE HISTORIES

EXAMPLES OF PREVIOUS DOCUMENTED EXPOSURES TO LOW FREQUENCY NOISE:

a. Flight Line and Engine Test Personnel

Maintenance and other operational personnel working in the immediate vicinity of turbojet aircraft or engine test stands are frequently exposed to noise spectra (See Figure 5) which approximate or exceed those levels estimated for the Apollo command module during max q normal launch. Exposures often last for ten to fifteen minutes or more and are usually longer than the one to two minutes during which the Apollo astronauts will experience high noise levels. Further, these personnel may be exposed repeatedly during the work-day and week rather than on a one-time basis.

Many noise fields substantially higher than those estimated for the Apollo command module are considered unpleasant and to be avoided whenever possible by the thousands of persons whose work involves such exposures. The sound energy is felt throughout the body and fatigue over and above that to be expected from the physical and mental exertion demanded by the task follows long exposures to high-level noise. Only the organ of hearing is susceptible to true physiological injury resulting from these exposures, however, and hearing loss is entirely avoidable if available ear protection is properly used.

The providing of adequate two-way voice communication in noise fields such as those illustrated in Figure 5 is difficult compared to the situation in the Apollo vehicle because there is a great deal of energy in the speech frequency as well as the low frequency range. Through use of headphones and microphones well isolated by earmuffs and "muzzles", however, essential communication can be carried on.

In summary, few if any persons enjoy exposures to sound fields of the type shown in Figure 5. Nevertheless, once they become familiar with the

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sensations generated by very intense sound, workers do not hesitate to expose themselves as may be required. Performance is not impaired and they suffer no ill effects so long as adequate ear protection is used.

b. Bolt Beranek and Newman Study

In one brief study recently conducted by Bolt Beranek and Newman, Inc., (Ref 6) two subjects were exposed with a discrete frequency siren to moderately intense sound fields of 3 c/s and 23 c/s noise (see Figure 6). For the 3 c/s noise, both subjects were exposed to a SPL of 131 dB for periods of 10 minutes and one hour. The subjects were exposed to the 23 c/s noise at a level of 125 dB for periods of 10 minutes, 30 minutes and one hour. One subject was also exposed for 10 minutes to 131 dB at 23 c/s. No ear protectors were used.

The subjects' hearing was tested by audiometer from 100-10,000 c/s immediately before and after each exposure. During the period of the exposure, electrocardiogram recordings were made. Also, before and after each exposure an otoscopic examination was made of the eardrums of the subjects.

No significant measurable hearing loss was found for any of the exposures which could be attributed to the 3 c/s or 23 c/s excitation. In the case of exposure to the 3 c/s noise, however, a temporary threshold shift in hearing was observed which was shown to be due solely to spurious low-level sound frequencies above 1200 c/s present in the sound from the siren. The subjects' heart rates did not perceptibly change before, during or after exposure except momentarily for the initial onset of the test environment. Otoscopic exams were negative. The results also indicate that these particular low frequency sounds did not interfere with speech nor did they cause any undue annoyance or discomfort on the part of these two subjects.

c. NASA-Langley Thermal Structures Tunnel

Personnel at NASA-Langley are on occasion subjected to the noise produced by blowdown operations of the Thermal Structures Tunnel (Ref 3). The spectrum produced at an adjacent laboratory building is shown on Figure 6. Some personnel normally occupying this building prefer to leave during the brief test runs and protect their ears with their hands; others remain. It is understood by this Laboratory that observers frequently view the tunnel operations from this vantage point out of doors.

d. Saturn Launchings

Large rocket launch operations are another source of low frequency noise. Two typical spectra generated by the Saturn booster vehicle (SA-1) are presented on Figure 6. Those levels produced approximately two miles from the launch pad were measured at Central Control where hundreds of persons witnessed this and similar launchings while unprotected and out of doors. Certain operational personnel are sometimes located as close as one mile to the launch pad and are exposed without protection. No adverse effects of such exposure have been reported to this Laboratory's knowledge.

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e. Aural Pain Threshold

The threshold of pain for the human ear has been studied from 3 c/s to 2000 c/s and for static pressure (Ref 5). This threshold, reproduced in Figure 7 was obtained at the low frequencies by exposing the ear alone to the pressure changes of a small pistonphone. Below approximately 20 cps, the pain threshold shifted to higher SPL's with decreasing frequency. Although these data naturally are of no value in assessing the effect of whole body exposure to low frequencies, they are valuable insofar as mechanical hazard to the ear as such is concerned.

AMRL EXPOSURE OF TEST SUBJECTS TO LOW FREQUENCY NOISE:

a. Methods

Four human test subjects were exposed to three progressively more severe noise environments (Tests 1, 2 and 3, respectively) for lengths of time ranging from 1 to 5 minutes. The preliminary system review (medical history), physical examination, and audiometric findings were normal for each subject. Table II contains pertinent demographic and anthropometric data.

TABLE II

Subject	Sex	Age in Years	Height in Inches	Weight in Pounds
(1) GM	Male	34	74	195
(2) JS	Male	39	76	194
(3) WG	Male	45	71¼	180
(4) HB	Male	24	68½	145

Ear protectors (plugs and muffs) were worn during all exposures. Data collection during Tests 1 and 2 included a continuous Sanborn record of pulse and respiration rates, clinical assessment of visual, labyrinthine, intellectural, and fine motor function, and evaluation of subjective responses. Test 3 data were limited to subjective and gross clinical observations.

b. Test Environments

Before reporting the effects of exposure, the three test environments shown on Figure 8 will be briefly described:

Test 1: The estimated spectrum within the command module during max q normal launch conditions was approximately simulated in a 5,000 $ft.^3$ reverberation chamber using the AMRL high intensity sound system. As the subjects moved about within the chamber, they were exposed to the range of levels indicated on Figure 8. Limitations in the power handling capacity of the system precluded achieving the desired levels at the low end of the spectrum. Attempts to suppress and compensate for resonances in the system and test chamber below 100 c/s were only partially successful.

The Test 1 spectrum shown on Figure 8 is based on an octave band analysis. In order to determine the irregularities in this spectrum in more detail, a 1/3 octave band analysis of this same data was accomplished with the results given on Figure 9. The irregularities evident in this spectrum are directly attributable to the aforementioned resonances and limitations of the system and test chamber. But even with this finer resolution, no particularly significant deviations from the desired test spectrum are evident. Furthermore, it is difficult to justify being too particular about the smoothness of the test spectra in view of the fact that the actual spectra produced within the command module will unquestionably have many peak and valley deviations from the predicted smooth average spectra. These detailed spectral characteristics cannot be predicted with any high degree of accuracy.

Test 2: Again the AMRL high intensity sound system was employed. However, instead of programming the system with the full bandwidth spectrum, octave bands of white noise were used one at a time, as input to expose the subjects to the seven bands of noise shown on Figure 8. Insofar as the capabilities of the system would permit, the levels at the band center frequencies were set approximately 10 dB higher than those estimated within the command module during max q normal launch. The spread in levels represents the range of SPL in each band as measured at different locations in the central portion of the test chamber.

The comments under Test 1 concerning the irregularities in the actual spectrum of the test environment are also applicable regarding Test 2. That is, the spectrum level throughout the frequency range of each octave band is not perfectly flat especially in the three bands lowest in frequency.

Test 3: The third and final test environment in this study was the most severe as seen on Figure 8 in that the spectrum levels exceeded those estimated within the command module by 13 to 20 dB over the entire frequency range considered. This environment was produced by an F-102 turbojet aircraft operating with afterburner. Subjects were placed at a location approximately 25 ft. offstream and 50 ft. downstream of the tailpipe. At this location, the noise spectrum is similar in shape to that estimated in the command module. The ability to obtain such a spectrum from a turbojet engine of this size comes from the fact that the region described is in the immediate proximity of the large scale, fully developed, turbulent mixing of the jet exhaust with the surrounding static air. Although the subjects were close to the flow boundary of the jet, at no time were they exposed to significant convected flow or abnormal temperature environments.

c. Effects of Exposure

Figures 10-13 provide a graphic display of the pulse and respiration rates during Tests 1 and 2. The subjects were permitted to move about freely, and, at intervals, to perform moderate physical exercise. No consistent variations in pulse or respiratory rate attributable to the noise exposure were observed.

Clinical observations were uniformly normal. Table III summarizes the pertinent data for Tests 1 and 2.

TABLE III

Function	Measurement	Subjects Normal	Subjects Abnormal
Vision	Dial Reading	4	0
Equilibrium	Rhomberg Test One Leg Stand	4	0
Position Sense	Finger-Nose Test	4	0
Concentration	Reverse Sevens	4	0
Fine Finger Dexterity	Writing Figure Tracing	4	0

Subjective responses during Tests 1 and 2 revealed no adverse effects. There were no reports of vertigo, nausea, air hunger, pain, disorientation, interference with phonation, or psychological unpleasantness. Vibration of body hairs occurred with exposure to the 25, 50, and 100 c/s (center frequency) bands. This response produced a sensation of air motion. With these same frequencies, a perceptible chest vibration was felt; however, it was in no way uncomfortable.

Subject response to the Test 3 profile was similarly unremarkable. The pulse rate of subjects 1 and 2 remained stable before, during, and after exposure. Subject 3 reported a sensation of tooth vibration. Subject 4 reported an "awareness" of his respiratory excursions. No subject experienced any perceptible decrement in visual or labyrinthine function. Although the sound pressure was distinctly felt by each subject, there was no reported occurrence of pain, nausea, vertigo, or disorientation. All subjects concurred that the Test 3 profile was completely tolerable.

Special tests to establish effectiveness of voice communications were not considered necessary. During the work involved in calibrating the noise fields for Tests 1 and 2, several technicians and others noted no difficulty whatsoever with voice communication through a standard H-157 or H-78 headset microphone. Further, direct speech using a loud voice was possible in the noise fields of Tests 1 and 2. Use of ear protectors did not hinder speech perception. The protectors were noted to be relatively ineffective against the very low frequency noise, although they of course were effective and mandatory in the noise fields of Test 3.

SECTION V

CONCLUSIONS

The noise levels predicted external to and within the Apollo command module during launch have been presented herein. These estimates (Ref 1) are considered to be adequate and reasonable by this Laboratory after analyzing and comparing these results to generalized empirical data available. The external levels estimated are believed to be accurate within ± 5 dB. The levels predicted within the module are somewhat more subject to error because of the additional uncertainty in estimating the command module attenuation. It would appear, however, that conservative values (i. e., low values) of structural attenuation have been estimated for the module at least as compared with the Mercury capsule.

North American Aviation has recently indicated (verbal communication with Mr. Clay Stevens, NAA, 31 Dec 63 and 8 Jan 64) that they still consider their estimates of low frequency structural attenuation to be valid even though the proposed design of the structure has been somewhat modified. North American will be conducting acoustic tests with representative structural panels to further validate these attenuation estimates. In any case, it is not believed that the average attenuation will be lower than 10 dB below the estimate on Figure 3.

Comparing the estimated Apollo levels with those of some other present-day operational situations (aircraft, rocket launchings, etc.), it becomes apparent that these Apollo levels are frequently no more severe. Even assuming that the error considered above results in a maximum total error of 15 dB (improbable), still does not place the expected Apollo environment completely outside the range of present experience.

To further evaluate the human response to these projected environments, controlled Laboratory exposures of four subjects were accomplished. Starting with an environment approximately that estimated for within the command module, during max q normal launch, the subjects were exposed to three increasingly more severe environments with the same relative spectral content. The highest levels to which the subjects were exposed (with only ear protection and normal clothing) ranged from 13 to 20 dB higher (frequency dependent) than the best estimates of the Apollo environment. The time duration of exposures were from one to five minutes, the latter time period considerably exceeding the high noise phase of the vehicle mission. In all cases, no significant effects were observed which would give basis to any undue concern over the Apollo low frequency noise environment from the human exposure viewpoint. All evidence based on the various known exposure histories points to this same conclusion for the levels estimated in the command module, even considering the maximum error margin probable.

Based on this evaluation, AMRL does not believe that at this time further requirements exist to expose subjects to higher level, low frequency SPL's to establish tolerability insofar as the Apollo mission is concerned. Actual SPL's in the Apollo command module should be established as early as possible.

In view of the still higher SPL's to be expected in the future with higher thrust rocket engines, a longer range effort is now under way in this Laboratory to attack the more basic questions of how the whole human body and its subsystems respond to such forcing functions and to establish, insofar as practical without damage to subjects, the upper limits of psychophysiological tolerance.

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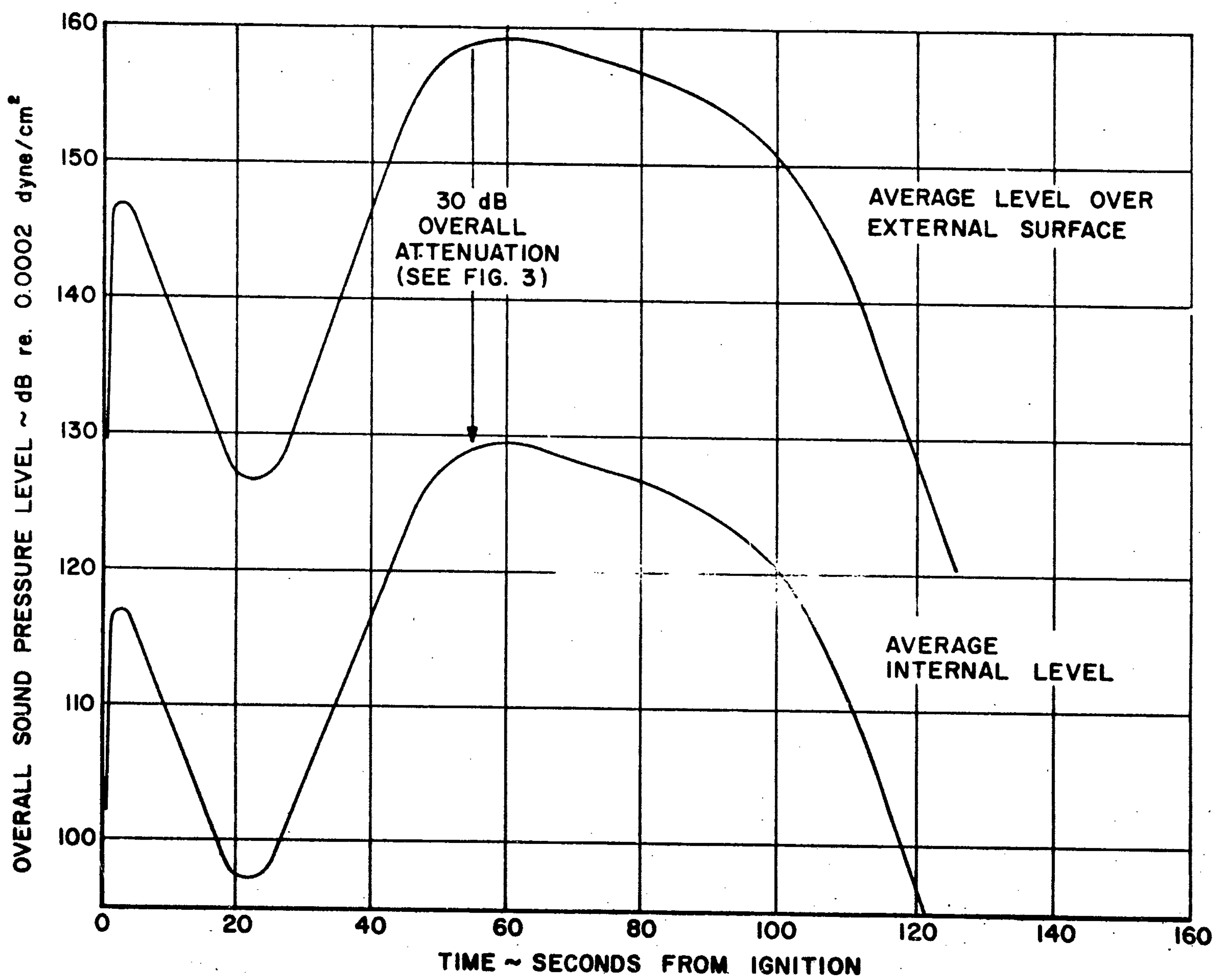

FIGURE I. ESTIMATED OVERALL SOUND PRESSURE LEVEL ENVIRONMENTS OF COMMAND MODULE AS A FUNCTION OF TIME (After Ref. 1)

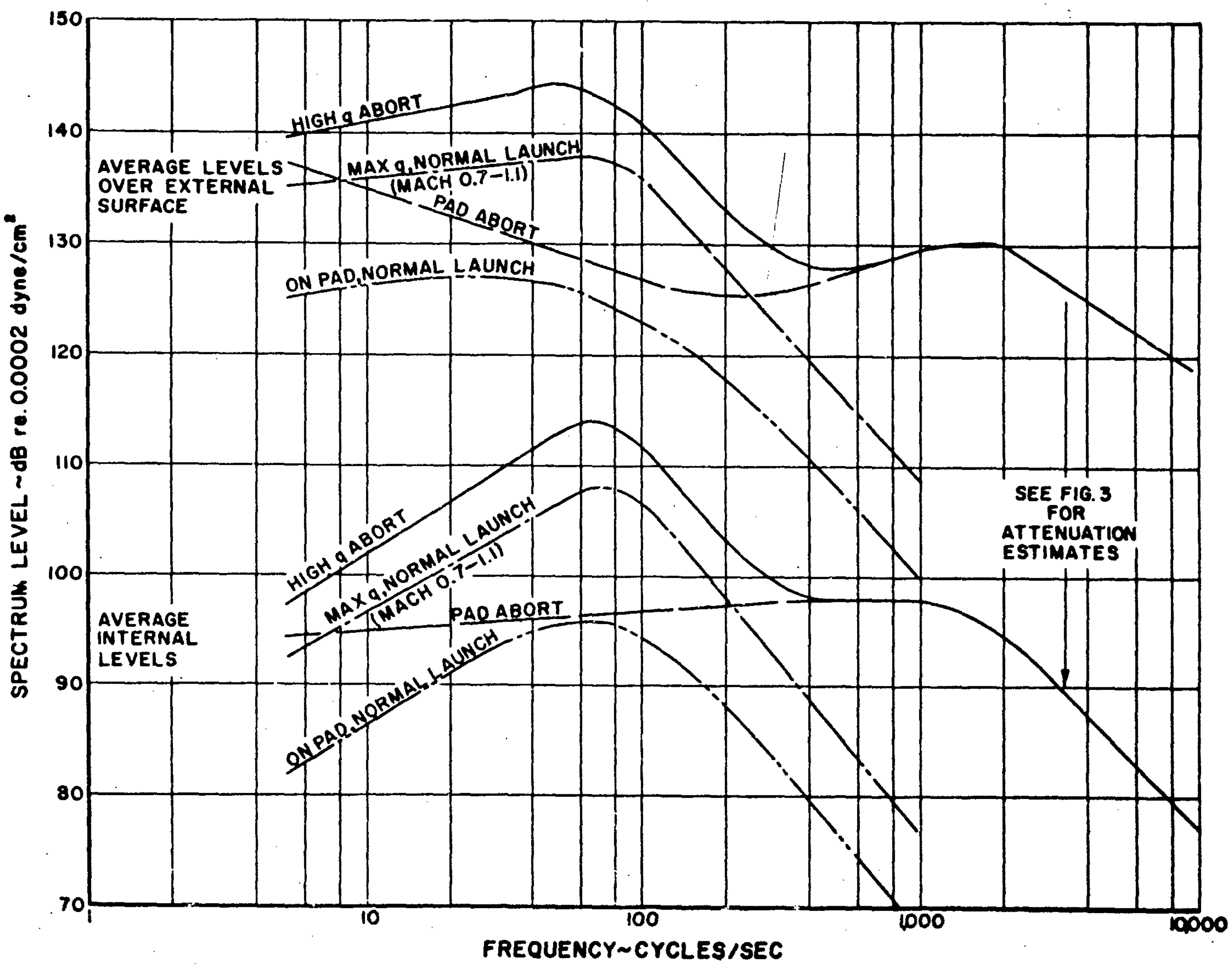

FIGURE 2. ESTIMATED SPECTRA OF NOISE EXTERNAL TO AND WITHIN COMMAND MODULE DURING SEVERAL OPERATIONAL CONDITIONS. (Based on Octave Band Levels — Ref. 1)

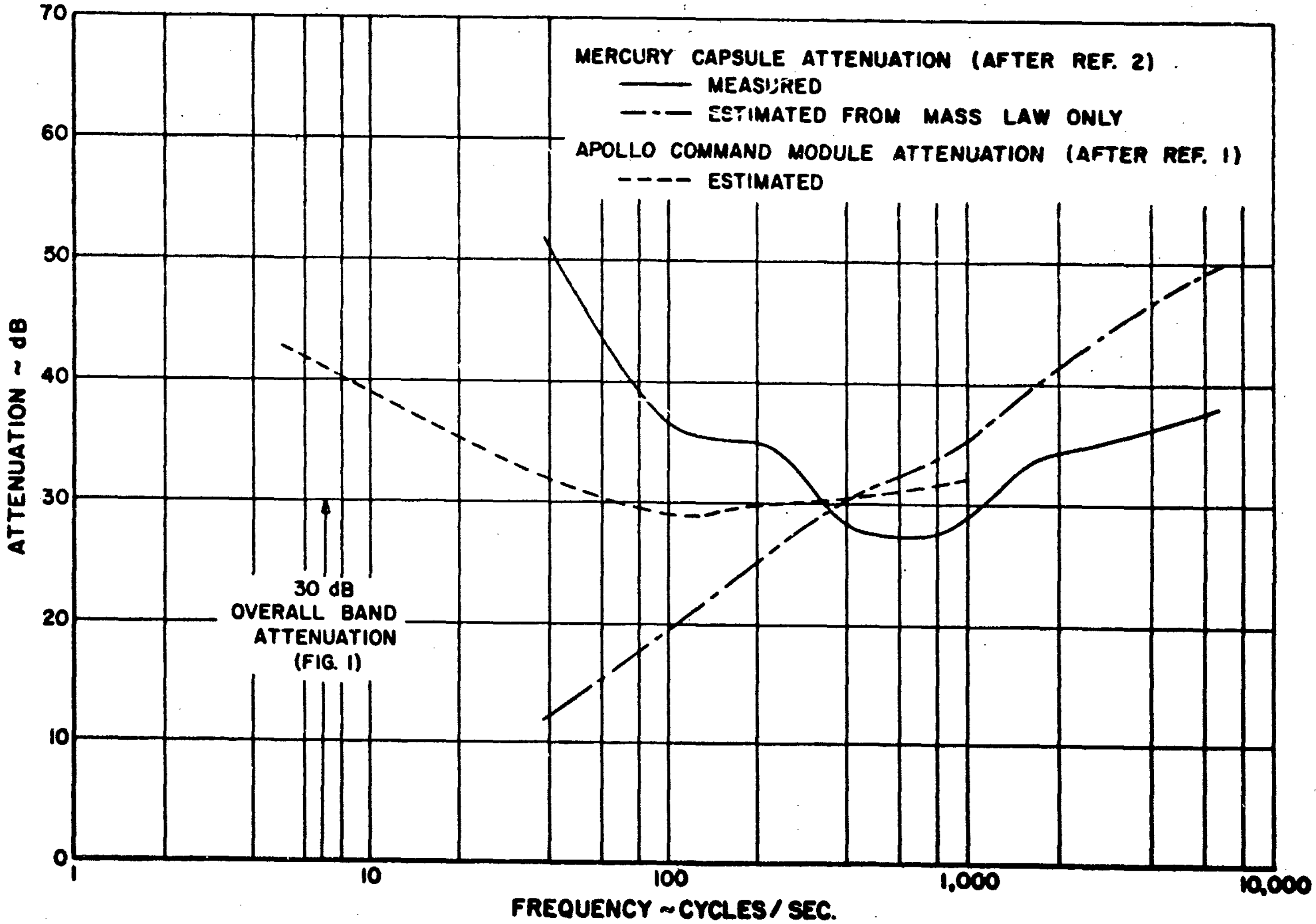

FIGURE 3. ESTIMATED NOISE ATTENUATION OF COMMAND MODULE AS A FUNCTION OF FREQUENCY.

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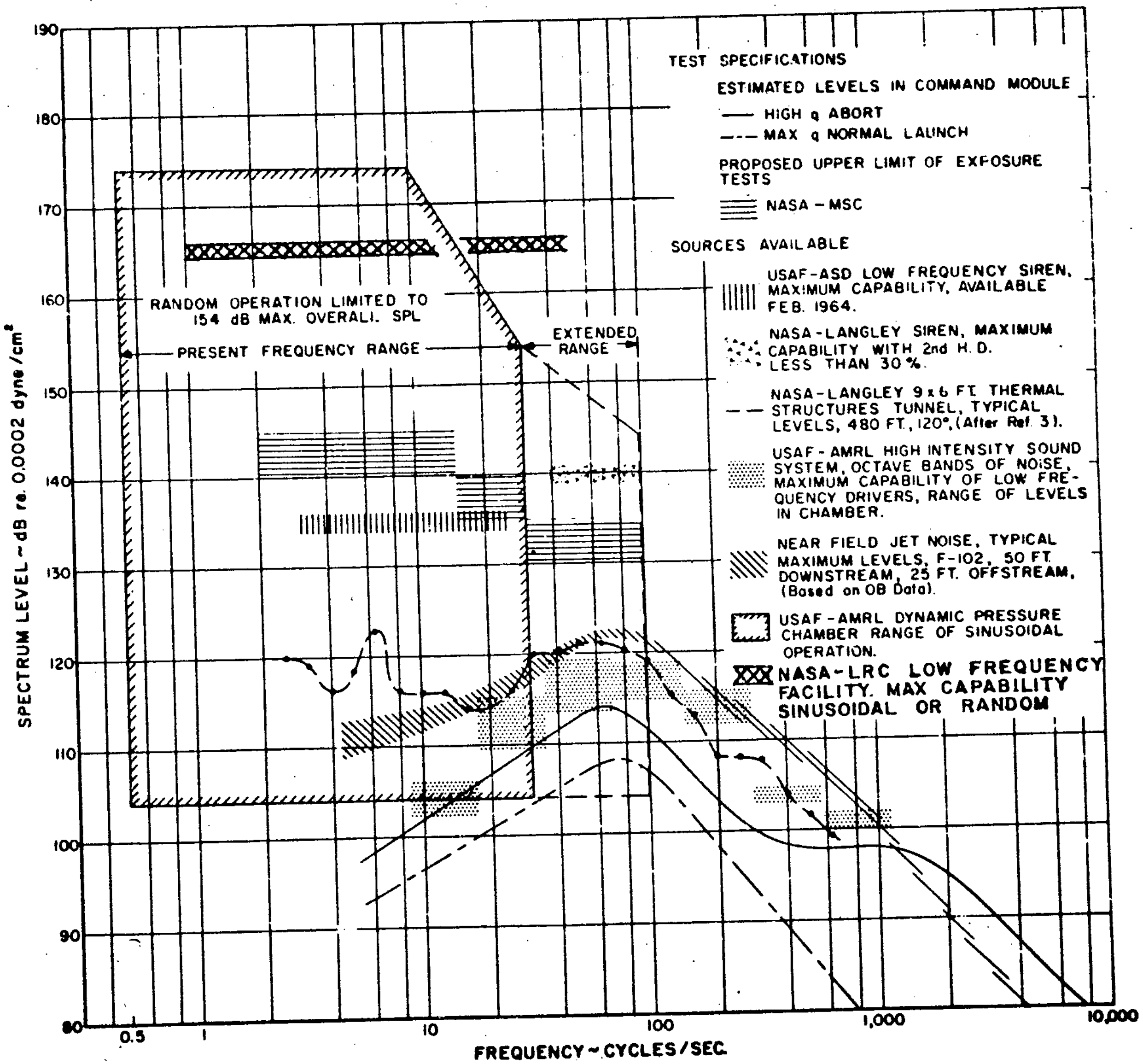

FIGURE 4. TEST SPECTRA REQUIREMENTS AND SOURCES TO SIMULATE NOISE IN COMMAND MODULE

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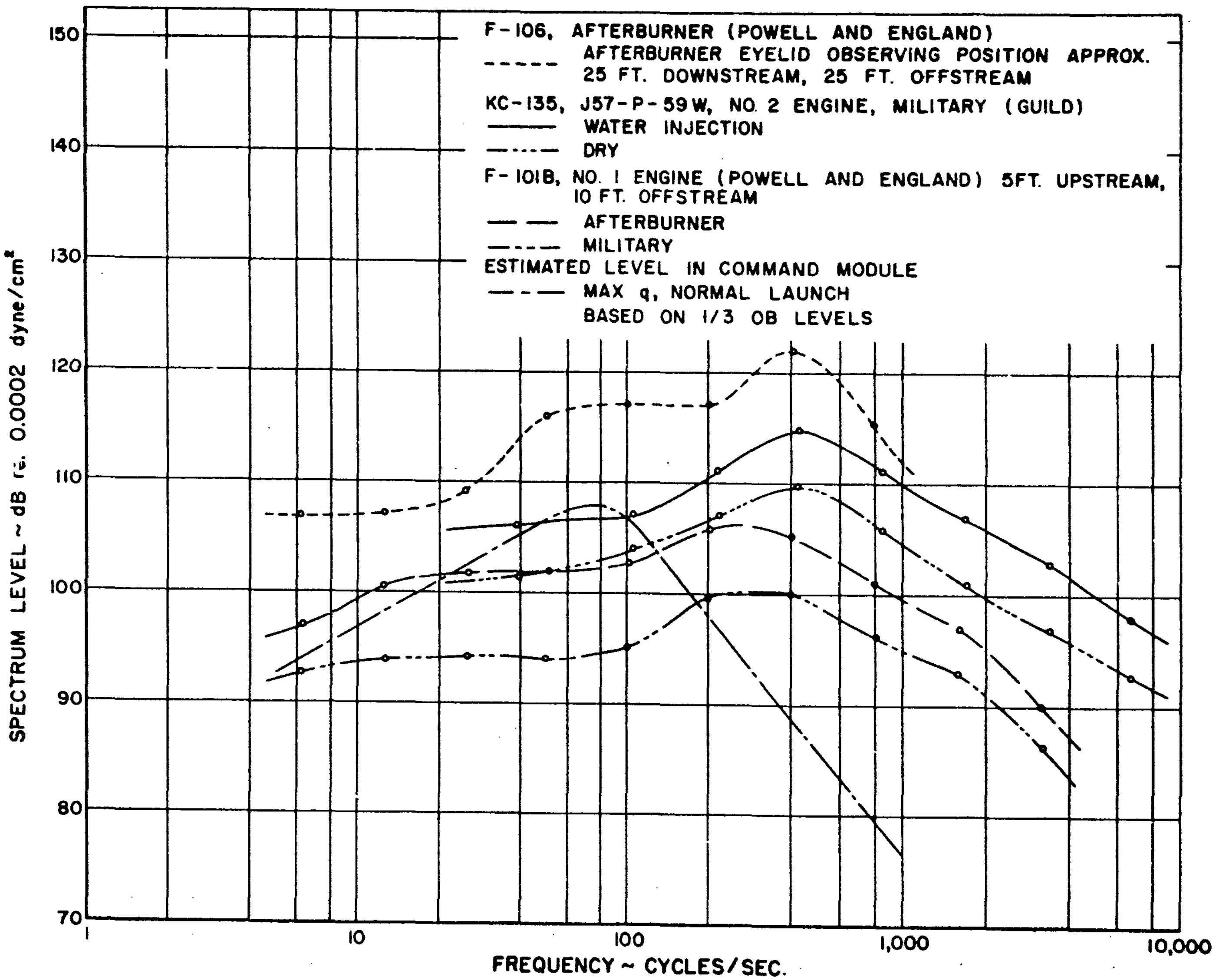

FIGURE 5 TYPICAL LOW FREQUENCY NOISE ENVIRONMENTS TO WHICH OPERATIONAL PERSONNEL ARE EXPOSED AROUND TURBOJET AIRCRAFT (All Levels Based on OB Data except as noted.)

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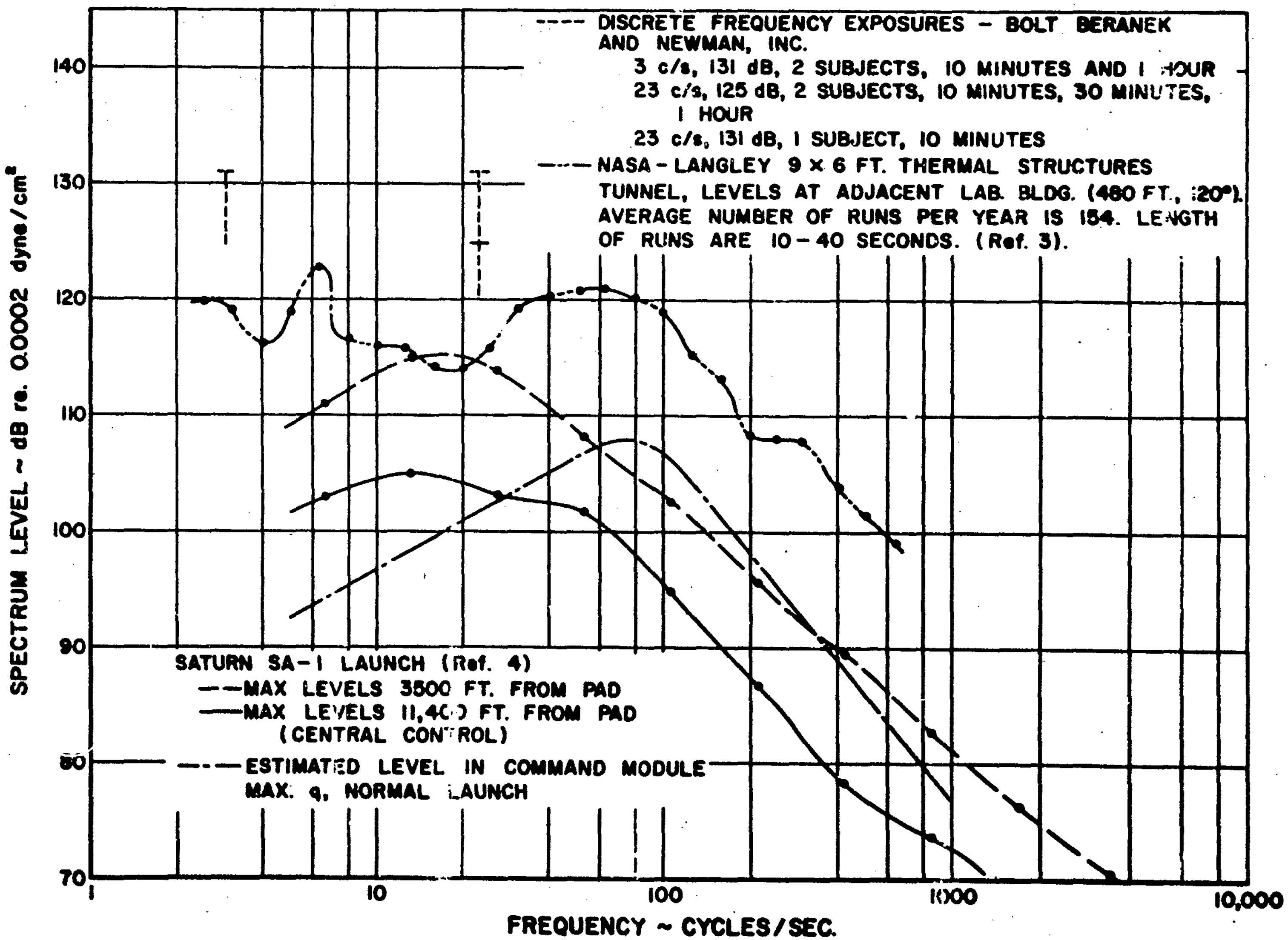

FIGURE 6 OTHER KNOWN CASES OF LOW FREQUENCY NOISE EXPOSURE.

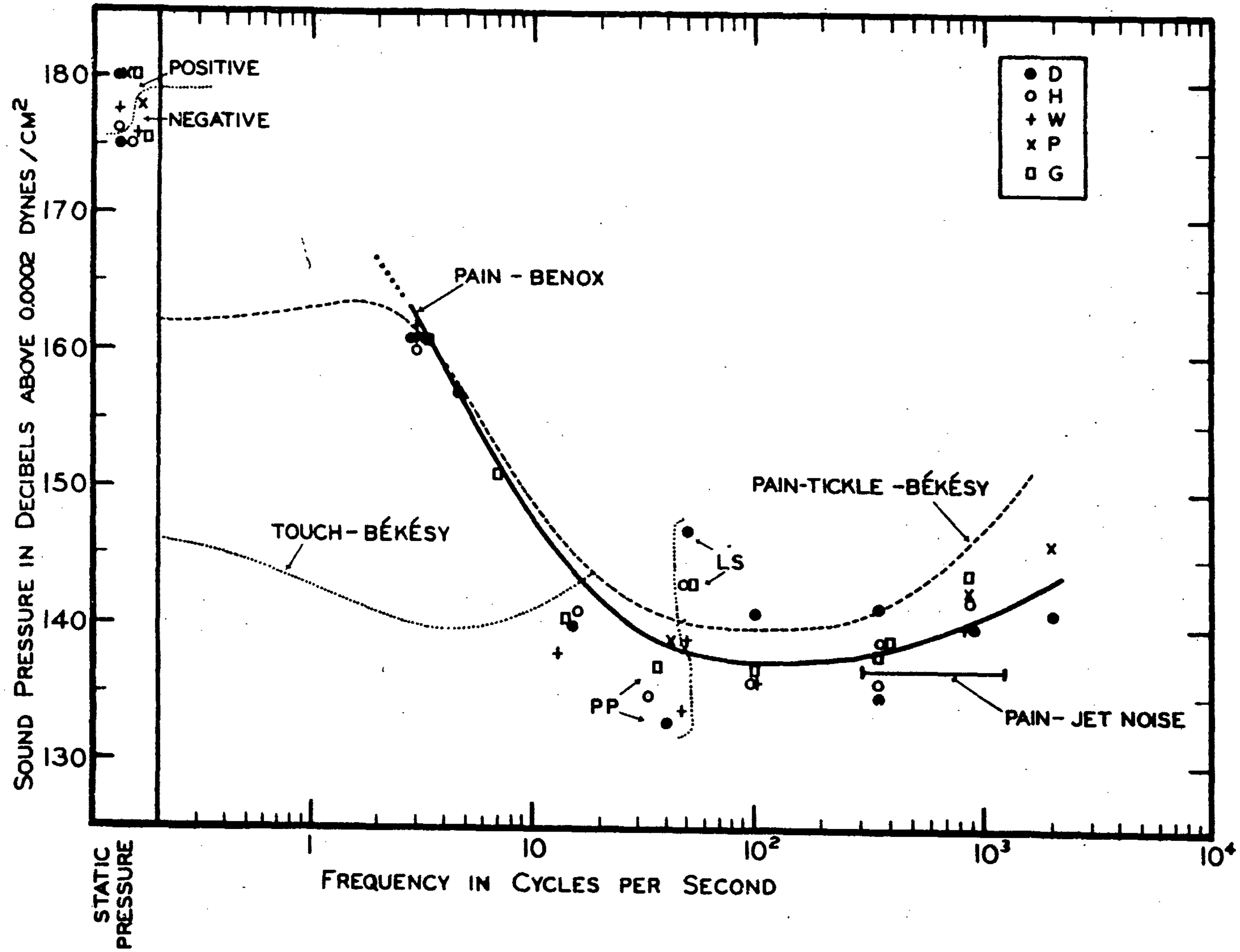

Fig. 7. Thresholds for aural pain produced by pure tones and jet noise. Points represent means of 3-4 determinations. Duplicate points represent means taken on different days. Positive and negative static pressures in the external ear canal are referred to atmospheric pressure. Line representing jet noise threshold is placed at overall sound pressure level and extends to the frequencies of the octave bands (300-600 and 600-1200) carrying most of the sound energy. (Touch and Pain-Tickle thresholds after Bekesy.)

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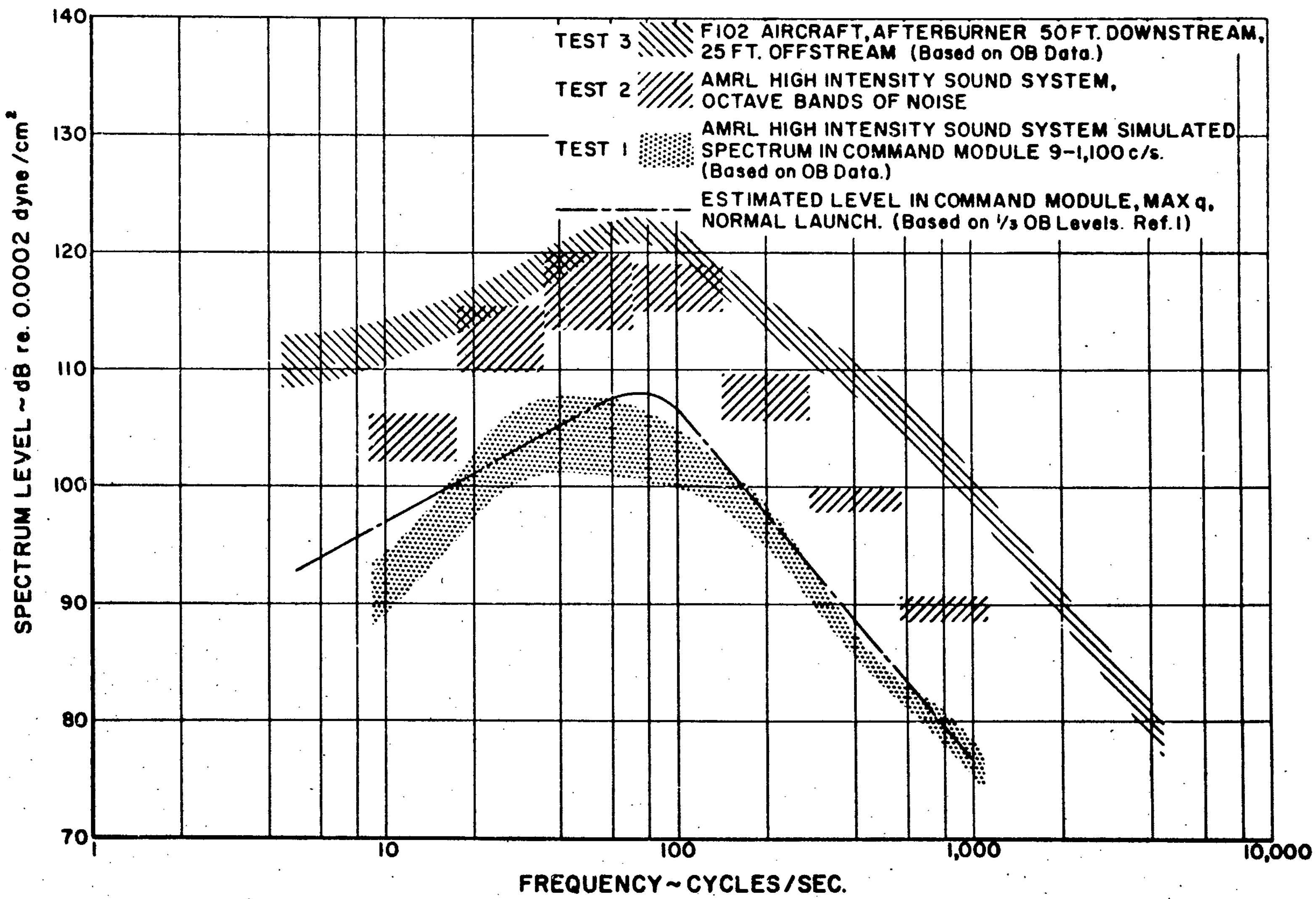

FIGURE 8 TEST ENVIRONMENTS USED IN AMRL LOW FREQUENCY EXPOSURE STUDY-PHASE I, NOV.-DEC. 1963

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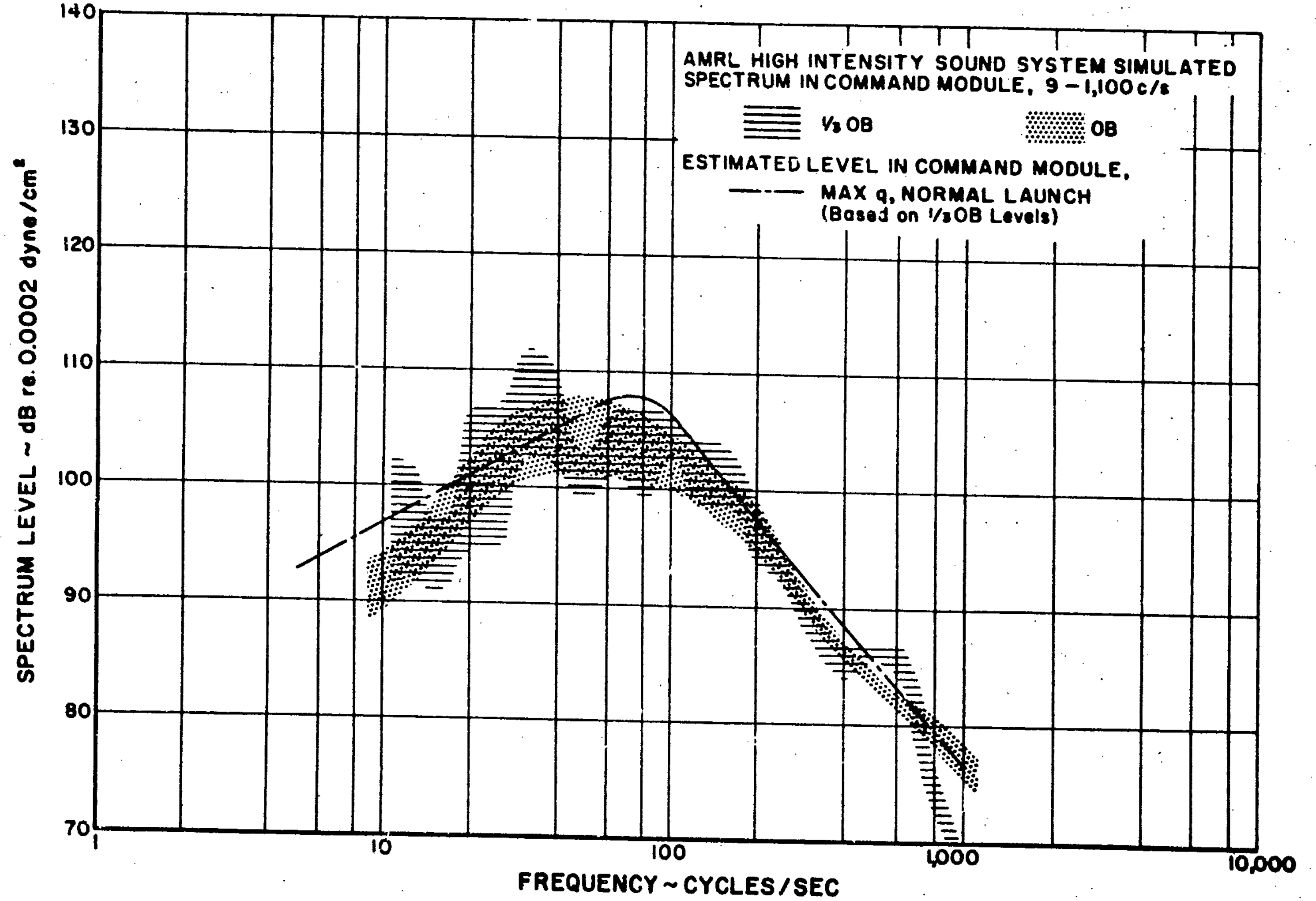

FIGURE 9 COMPARISON BETWEEN OB AND 1/3OB ANALYSES OF AMRL'S SIMULATION OF SPECTRUM IN COMMAND MODULE.

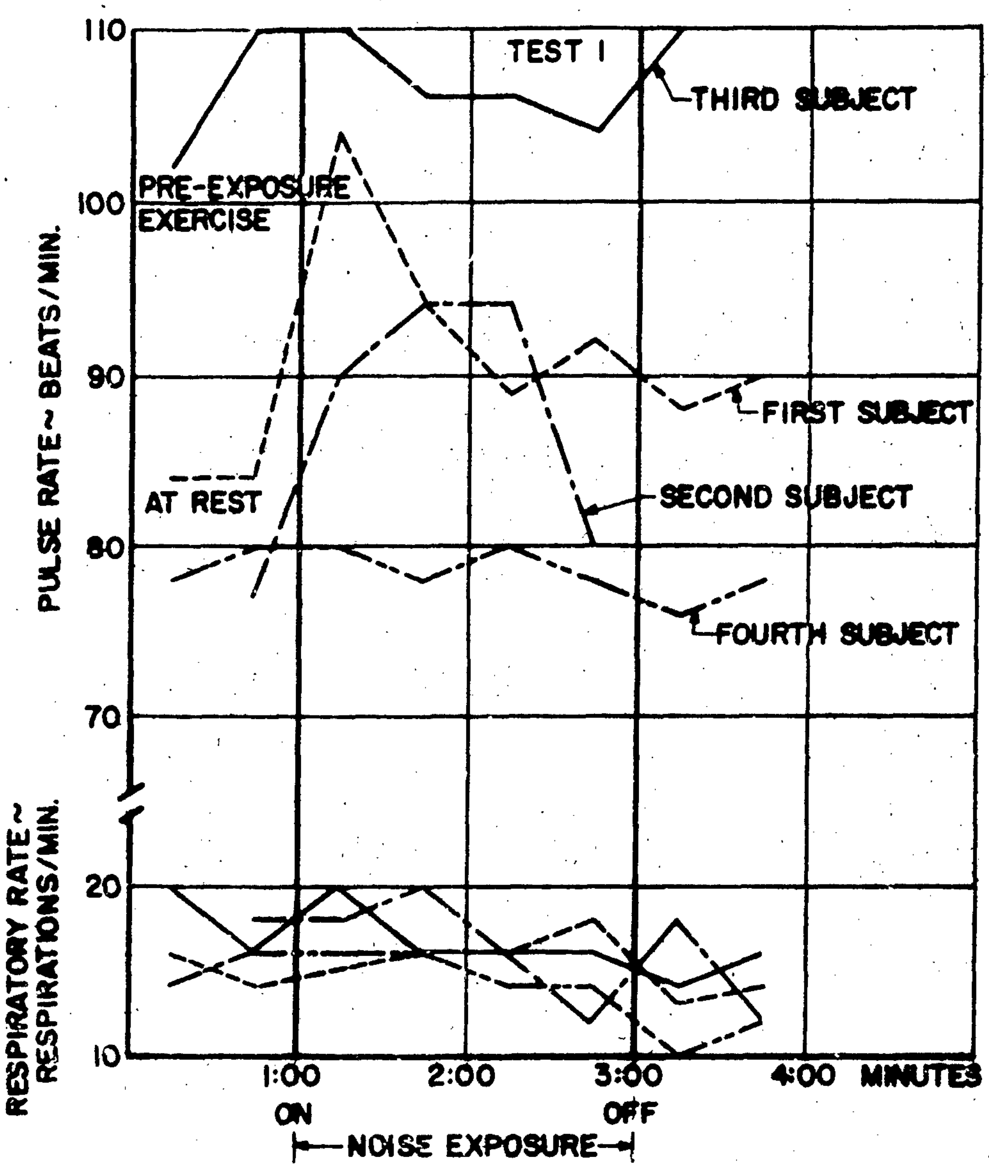

FIGURE 10 RESPONSE OF FOUR HUMAN SUBJECTS TO A TWO MINUTE EXPOSURE TO THE SIMULATED APOLLO NOISE SPECTRUM.

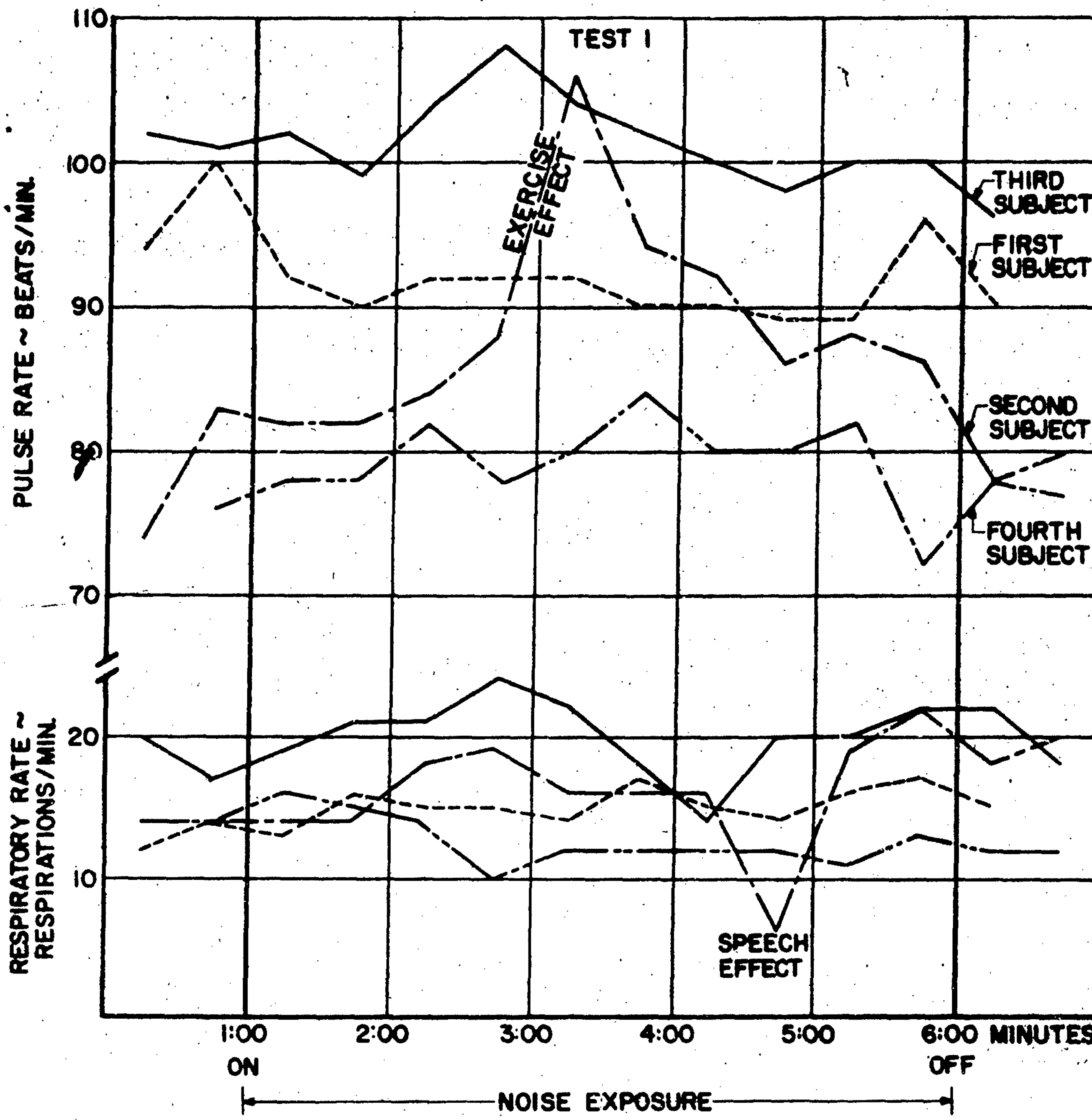

FIGURE 11 RESPONSE OF FOUR HUMAN SUBJECTS TO A FIVE MINUTE EXPOSURE TO THE SIMULATED APOLLO NOISE SPECTRUM.

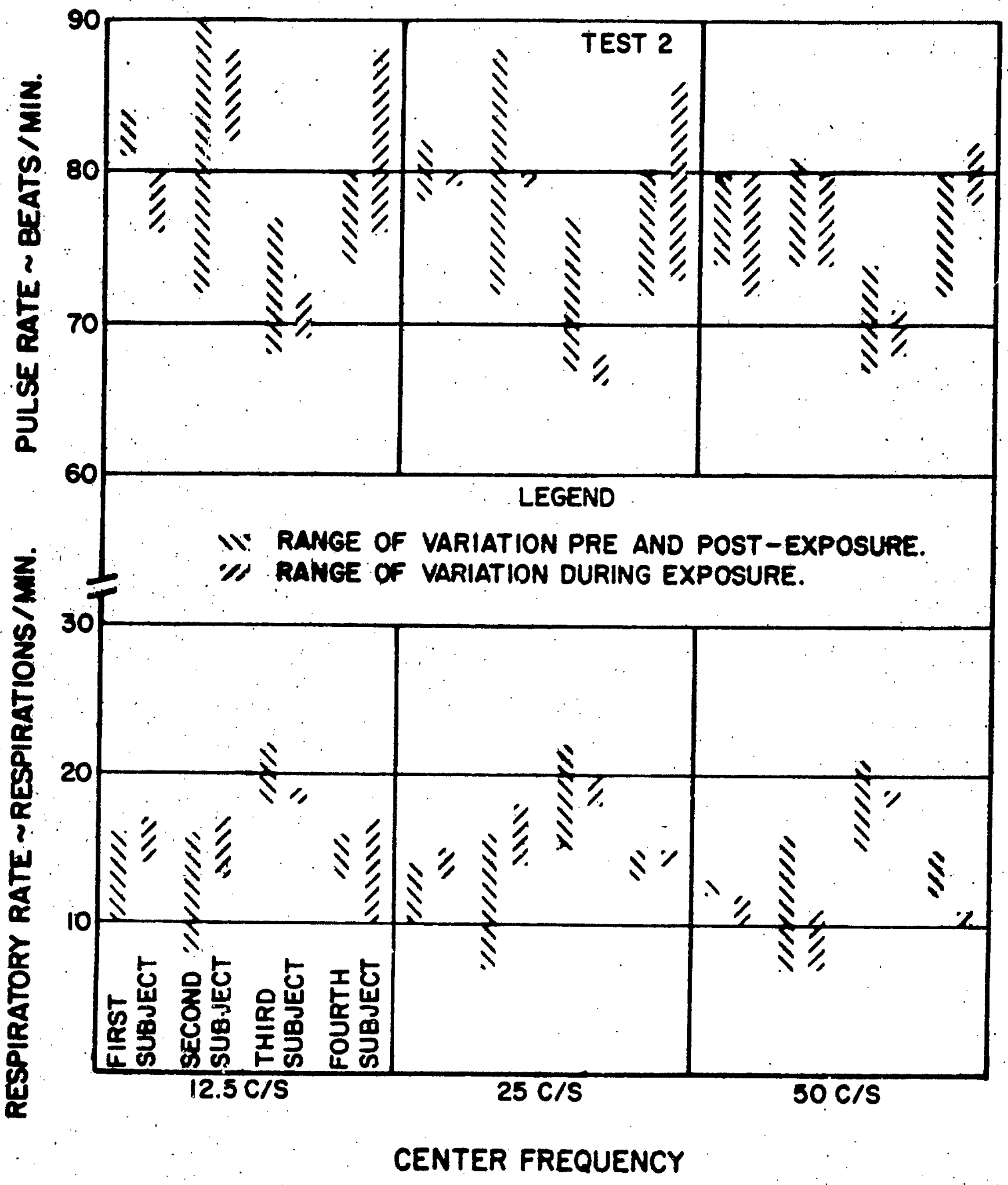

FIGURE 12 HUMAN RESPONSE TO OCTAVE BANDS OF NOISE, TWO MINUTES DURATION, INTENSITY 10 dB GREATER THAN THE ESTIMATED APOLLO NOISE LEVEL.

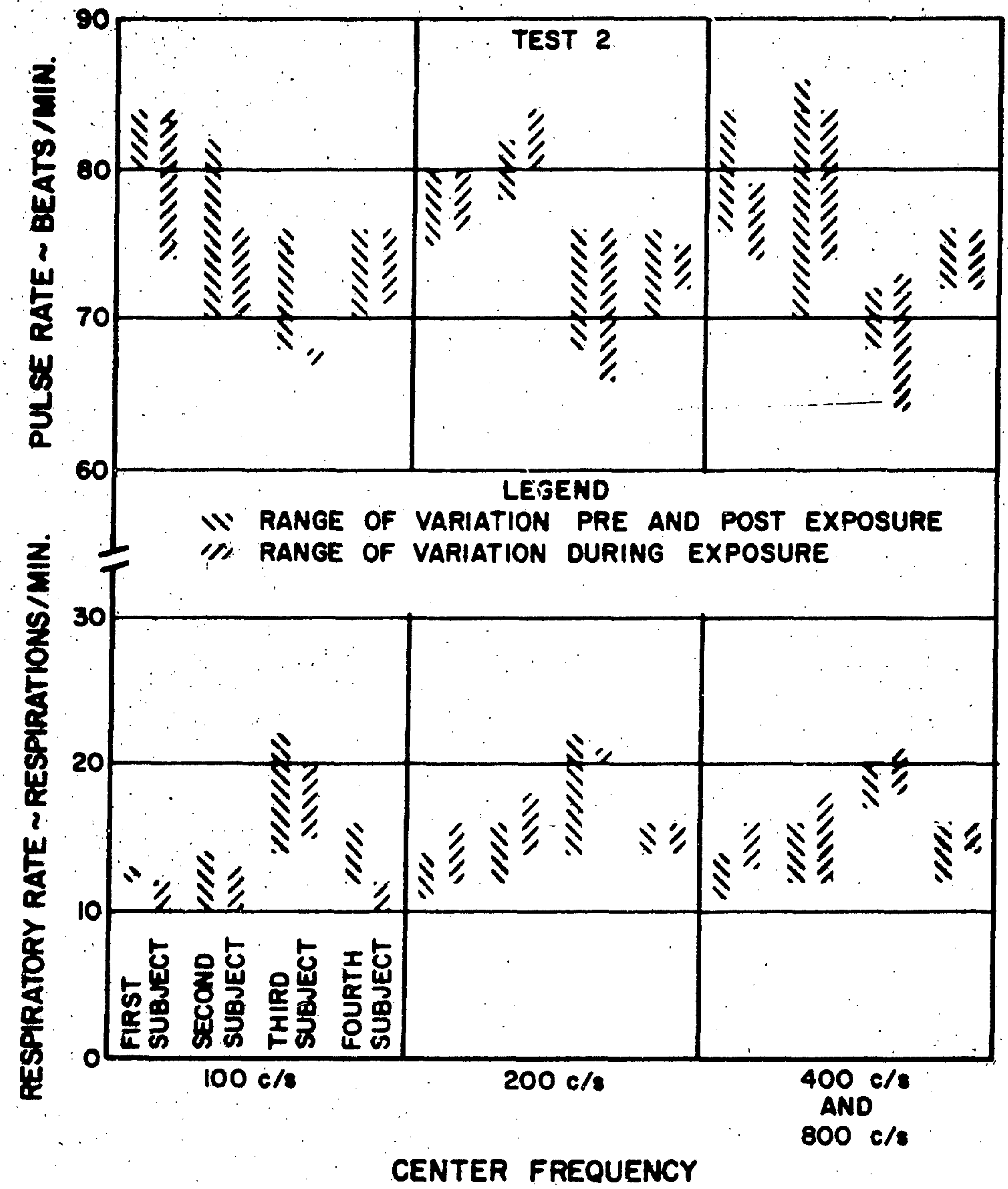

FIGURE 13 HUMAN RESPONSE TO OCTAVE BANDS OF NOISE, TWO MINUTES DURATION, INTENSITY 10 dB GREATER THAN THE ESTIMATED APOLLO NOISE LEVEL.

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